Measurement and comparison of risk reduction by means of farm yield, area yield, and weather index crop insurance schemes - The case of Kazakhstani wheat farms

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Introduction

Traditional insurance schemes which cover farm yield risk face problems of asymmetric information. Index insurance contracts, such as area yield insurance or weather index insurance, may overcome these problems. At the same time, providing insurance against systemic risk, index insurance schemes do not insure farmer's idiosyncratic risk. This induces the problem of basis risk. Risk reduction potential of index insurance contracts depends strongly on the extent to which individual farmers are affected by systemic risk and their risk attitude. Hence, introduction of index insurance schemes into the market must be preceded by analysis of whether farmers' risk reduction through selected insurance products is sufficient to generate substantial demand for these products.

Recent discussion in literature focuses on insurance schemes based on weather indexes (ANDERSON, J. R.; SKEES, HAZELL, MIRANDA; VARANGIS, SKEES, BARNETT; OECD). Use of aggregated data can underestimate farm idiosyncrasies and, presumably, overestimate the demand for these insurance products. Nevertheless, empirical analyses of weather index insurance based on farm level data cannot be found in the literature to the best of authors' knowledge.

In addition, analyses of area yield insurance contracts use a method that is not necessarily consistent with expected utility theory, and do not allow for statistical inference among the insurance contracts.

The objective of this paper is threefold: From a methodological perspective, (1) in a manner consistent with expected utility theory, to introduce an innovative, though straightforward approach for empirical assessment of the optimal insurance hedge ratio. (2) By employing bootstrapping, to determine insurance products which, compared with alternative insurance schemes, generate significantly higher risk reduction for individual farmers. From an empirical point of view, (3), the paper aims to compare the risk reduction effect of weather index insurance with that of established crop yield insurance products such as farm yield and area yield insurance.

We start by reviewing the literature, presenting the decision model and empirical methods applied. We proceed by describing wheat production in Kazakhstan and the data used. This is followed by presenting and discussing empirical results. Finally, we draw conclusions which can be relevant for academics as well as insurance providers.

Literature on crop yield insurance

To determine risk reductions, which crop yield or weather insurances can provide to the farmer, common hedging theory is appropriate. Most empirical analyses assess the agent's optimal hedging strategy by JOHNSON's hedging model, based on the mean-variance (MV) approach. MIRANDA develops a general model for crop yield insurance based on JOHNSON and applies it to Kentucky soybean farms. SMITH, CHOUINARD, AND BAQUET as well as MAHUL AND VERMERSCH follow MIRANDA's main idea while extending the insurance schemes and applying them to wheat farmers in Montana and France.

MIRANDA assumes a farmer who can only choose the crop insurance coverage level. Since exogenous production decisions and costs, a certain output price, and a fair insurance premium are assumed, farmer's i utility is maximised by minimising his revenue variance $Var[\pi_i]$ where π_i is the insured revenue

(1) $\pi_i = y_i + z_i\, n - z_i\, E[n]$,

where y_i is the farm yield per area unit, $z_i \geq 0$ is the coverage level chosen by the farmer, n is the indemnity payment, $E[\ ]$ is the expectation operator, and the output price is set to unity. Because revenue is a linear combination of the farm yield and indemnity payments, the combination's variance is minimised for the coverage level $z_i{}^*$ per area unit, which equals the negative linear estimator of regressing the farm yield on the indemnity payments. Thus, $z^*_i = -Cov[y_i,n] / Var[n]$ (JOHNSON). The indemnity payment n is defined as $n = Max[x_t - x, 0]$, where x is an index. It is an area (farm) yield in case of area (farm) yield insurance and it is a weather index in the case of a weather index insurance. In case of a farm yield insurance the trigger value x_t should be less than the expected yield and z_i should be less than one to ensure a deductible and a coinsurance, respectively to reduce moral hazard incentives.

Empirical analyses of weather index insurance for farm level data are, to the best of the authors' knowledge, not known. SKEES ET AL. using a rainfall-based insurance, report a reduction of 29% of the aggregated regional revenue risk measured by the coefficient of variation of a portfolio of several crops measured by their regional yield in 17 Moroccan provinces.

We think that the previous literature should be extended in two ways. First, the MV approach for analysing hedging decisions empirically might not be the appropriate theoretical base because it can be inconsistent with expected utility (EU) theory. This is especially true for highly risk-averse agents, because their relative high utility from low income compared to utility from high income is not necessarily reflected in the income's variance and the coefficient of absolute risk aversion. Thus, the optimal solutions of the MV approach are not necessarily optimal for an EU maximizing agent. However, if the data distributions of the risky choices fulfil the LS [location-scale] condition, MV and EU optimal solutions are equivalent (SINN 1980, MEYER 1989). The LS condition is fulfilled if two cumulative distribution functions (with and without insurance, or with different coverage levels) only differ in their mean and standard deviation. However, the LS condition cannot hold if insurance payments are added to a crop revenue distribution because insurance payments are truncated (e.g. MAHUL AND VERMERSCH). In addition, there is empirical evidence that crop yield distributions do not fulfil the LS condition, either (e.g. SHERRICK, ZANINI, SCHNITKEY, AND IRWIN; NORWOOD, ROBERTS, AND LUSK; RAMIREZ, MISRA, AND FIELD). As a second extension, we apply bootstrapping, because statistical inference is absent from the empirical crop insurance analyses presented above. Consequently, nothing is known about the statistical liability of the literature results, thus former analyses cannot discriminate between different insurance schemes in a statistically significant manner.

Model and Methods

From the previous section, we know that MV analysis is not necessarily consistent with expected utility (EU) theory for the analysis of crop insurance. After presenting the criterion of Second Degree Stochastic Dominance (SSD) we combine the MV approach with SSD for an EU consistent empirical procedure.

In addition to MV preferences, SSD is another risk preference measure. A risky alternative I described by the cumulative distribution function G(w) is said to dominate another risky alternative II described by the cumulative distribution function H(w) by SSD, if

(2) $$\int_{-\infty}^{x} H(w)dx \geq \int_{-\infty}^{x} G(w)dx$$ for all $x \in \Re$ and at least one strict inequality.

If an agent's utility is concave in w, SSD is consistent with expected utility (e.g. MOSCHINI AND HENNESSY). To obtain the optimal SSD coverage level z^{**}_i, we apply Levy's stochastic dominance precondition ["If two options (of wealth distributions) have the same mean, then the one with the greater variance cannot dominate" (p. 572)] and we get

(3) $$\min_{z} \; Var[\pi_i] \quad s.t. \quad G(\pi_i) \succ H(y_i),$$

where G(.) and H(.) are cumulative distribution functions and '$\succ$' means "second degree stochastic dominant over".

To solve (3) we assume a range of coverage levels the farmer can choose from, and compute πi for each z. The optimal coverage level z^{**}_i is chosen from all z according to (3).[1] However, another problem exists. If H is not SSD over G, we do not know which alternative is preferred by an agent. Thus, SSD is sometimes not a good decision-making tool because paranoiac risk

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[1] The mean-Gini approach can provide an analytical solution for (3) if *G* and *H* intersect at most once (SHALIT AND YITZHAKI). Since we want to avoid any assumptions on the distributional forms of the risky choices reliably, and because of the high basis risk of area yield instruments for some farms, it is not appropriate to restrict our analysis to an MG approach. See LIEN AND TSE for a literature review of the MG approach in futures hedging.

aversion is not excluded. Therefore, "it is quite possible for any two distributions that neither one stochastically dominates the other," (MOSCHINI AND HENNESSY, p. 96). We now suggest a combination of the MV and SSD approach.

Summing up, MV always gives a preference order, but it need not be consistent with EU, particularly for highly risk-averse agents. SSD preference orders are always consistent with EU for the most risk-averse agent, but SSD does not necessarily give the EU maximising preference order for any set of alternatives for any risk-averse agent. If the preference orders obtained from both approaches equal each other, we have a preference order that is optimal for the most risk-averse agent because of SSD, and it is optimal for agents with low but positive risk aversion because of the MV approach. Therefore, we get the sufficient condition that a preference order maximises EU for any risk-averse agent if the MV approach and the SSD approach both yield the same preference order. If the results (e.g. optimal coverage levels) differ from both approaches, we get an upper bound of the coverage level from the MV approach for agents with low risk aversion and a lower bound from the SSD approach for highly risk-averse agents.

For statistical inference, we propose the bootstrapping method because the form of the yield distributions is not known. Alternative tests for stochastic dominance from the literature are either parametric (KAUR, RAO, AND SINGH) or they assume large samples (ANDERSON, G.; DAVIDSON, AND DUCLOS). A nonparametric test of KLECAN, MCFADDEN, AND MCFADDEN (cited in ROOSEN AND HENNESSY) requires more than fifty observations in each distribution. Simulation results suggest that a permutation test procedure proposed by TOLLEY AND POPE is less powerful than bootstrapping.

Wheat Production in Kazakhstan

Wheat is by far the most important commodity produced in Kazakhstan: in 2004, 78% of its total crop area was sown with wheat (INTERFAX). Kazakhstan is the eighth largest world exporter of wheat, with a share of the world market that ranges from 2 to 3%. The use of less intensive technologies and the challenges of the market during economic transition have increased uncertainty and risk in wheat production. Kazakhstan is not only the producer with the greatest distance to any port but also one with considerably lower and more fluctuating yields due to drought. The coefficient of variation of national wheat yields for the period 1980-2004 is more than twice as high compared to other competitors with somewhat similar total areas planted with wheat, such as Canada, France, Germany and Spain.

Data

Yield data was collected by means of farm surveys and covers 84 large grain producers in eight counties in four regions, from 1980 – 2002. In 2002, the farms' wheat areas differ between a few hundred and more than 40,000 hectares. The considered farms represent 7.3% of the national wheat area in 2002. In five counties, the share of total wheat area represented by the farms surveyed accounts for more than 70%. In addition to farm data, the study uses official statistics on national and regional yields (REGIONAL STATISTICAL OFFICES AND NATIONAL STATISTICAL AGENCY) as well as weather data from 9 weather stations in the considered counties. Wheat areas in the selected counties differ from less than 50,000 hectares to more than 300,000 hectares. In 1998, a year of great drought, the weighted average yield amounted to only 0.40 tons, which is 46% of the average yield from 1980 – 2002.

To reflect the yield variability appropriately, data must be de-trended. While MIRANDA, as well as MAHUL AND VERMERSCH, account for linear time trends, we have longer yield time series from a transition country. In the case of Kazakhstan, the former state and collective farms were downsized and transformed into cooperatives, limited liability partnerships, joint stock companies and private family farms. Thus, wheat yields are adjusted for second-degree polynomial time trends and for structural breaks.

There is no structural break in the national yield at the significance level of 5%. Structural breaks of oblast yields, however, prevail in two of the four considered oblasts. In each of these oblasts, structural breaks are identified in one rayon each. Structural breaks are found in

21 of 84 farms, in most cases occurring structural breaks in 1991 and 1992, but also in 1997-1998. We can apply bootstrapping to only 36 farms because of autocorrelation.

Insurance instruments

We evaluate three main groups of insurance products: farm yield insurance (FYI), area yield insurance (AYI) and weather-based index insurance (WBII), and two futures: area yield and weather-based index futures. The analysis considers area yield insurance and futures at 3 different regional (national, state (oblast) and county (rayon)) levels. WBII products are designed based on a rainfall index, as well as the SELYANINOV and PED drought indices, respectively.

SELYANINOV (quoted in SHAMEN) suggested an index based on precipitation and temperature. He introduced the so-called hydro-meteorological coefficient (HTC):

$$HTC_i = 10\frac{\sum R}{\sum T}, \tag{4}$$

where ΣR is cumulative precipitation in mm during year i with an average daily temperature ≥ 10°C; ΣT is the sum of the average daily temperature in degrees Celsius in the same year.

Later on, PED (quoted in SHAMEN) suggested measuring drought by means of an index (S_i), which considers, in addition to precipitation and temperature, soil moisture:

$$S_i = \frac{\Delta T}{\sigma_T} - \frac{\Delta R_i}{\sigma_R} - \frac{\Delta Q_i}{\sigma_Q}, \tag{5}$$

where ΔT, ΔR and ΔQ stand for differences between long-term average and year i, precipitation and the productive soil moisture in a one-meter soil horizon in springtime, respectively; σ_T, σ_R and σ_Q are their long-term coefficient of variation.

To improve the performance of the selected indices, BOKUSHEVA modified them by introducing monthly data.[2] Since soil moisture is a parameter related to soil cultivation

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[2] Since plants' resistance to drought varies during growth phases, monthly data provide a basis for a more precise assessment of wheat yield dependency on weather conditions in the individual years.

intensity, using soil moisture as a parameter for an insurance product could induce moral hazard problems. Therefore, the PED drought index was modified by replacing data on soil moisture through data on cumulative precipitation in the period from September to May. The yearly values of the indexes xi are computed following equations (6) to (8).

Rainfall index

$$x_i^{Rain} = w_{May} R_i^{May} + w_{June} R_i^{June} + w_{July} R_i^{July} + w_{August} R_i^{August} + w_{Sept-April} R_i^{Sept-April} \tag{6}$$

Modified SELYANINOV drought index

$$x_i^{Sel} = w_{May} R_i^{May} + w_{June} \frac{R_i^{June}}{T_i^{June}} + w_{July} \frac{R_i^{July}}{T_i^{July}} + w_{August} \frac{R_i^{August}}{T_i^{August}} + w_{Sept-April} R_i^{Sept-April} , \tag{7}$$

Modified Ped drought index

$$x_i^{Ped} = w_{June} \frac{\Delta R_i^{June}}{\sigma_{R^{June}}} + w_{July} \frac{\Delta R_i^{July}}{\sigma_{R^{July}}} + w_{August} \frac{\Delta R_i^{August}}{\sigma_{R^{August}}} - w \frac{\Delta T_i^{June-August}}{\sigma_{T^{June-August}}} + w \frac{\Delta R_i^{Sept-May}}{\sigma_{R^{Sept-May}}} , \tag{8}$$

where R is the cumulative rainfall (or precipitation) in a particular sub period, T is the average daily temperature in an indicated subperiod, i is a year index and w represents a subperiod's weight, obtained from regressions of the right-hand side variables on rayon yields.

Results

First, we show the optimal decisions for the combination of the SSD and the MV approach. Second, we present the results from the area yield insurance schemes based on the national yield, oblast and rayon yields, respectively. Third, we show the results for the three analysed weather indexes. Finally, we compare the performance of a farm yield insurance, an area yield insurance, and a weather index for a subsample of farms that allows for the use of bootstrapping.

Graph 1 highlights the need to combine the SSD approach and the MV approach. Nearly one-third of the farms yield a variance reduction by means of MV, which is not necessarily consistent with expected utility theory for hedging with the SELYANINOV weather index with the strike value equalling its expected value. We can be sure for two-thirds of the farms that the computed variance reductions are consistent with expected utility theory without knowing anything about the distribution of the farm yields or the weather index. However, the need to combine is especially true for farms with low variance reductions. Above an expected variance reductions of 40%, both variance reduction of the MV and the SSD approach are equal for every farm.

Turning to area yield insurance contracts, the last row in Table 1 confirms the need to combine the MV and the SSD approach for area yield insurance as well. Between 14 and 22 of the farms do not realise variance reduction by means of area yield insurance based on the national, the oblast, or the rayon yield with the SSD approach. Therefore, we cannot know whether the variance reduction for these farms by means of the conventional MV approach is consistent with expected utility. Not surprisingly, rayon yield insurance outperforms the other area insurance schemes in terms of average relative variance reduction (42% for the MV approach and 40% for the SSD approach) and number of farms with a positive (non-zero) expected variance reduction. It is somewhat striking that the national yield insurance may outperform the oblast insurance, since oblast yields should be more closely related to the farm yields than higher aggregated national yields. The average relative variance reduction of rayon insurance is similar to the relative variance reductions by means of a regional wheat yield that MAHUL AND VERMERSCH report for a selection of 20 out of 124 wheat farms in northern France. The average relative variance reduction by means of the national wheat yield in our analysis (28%) seems to be substantially smaller than that of MAHUL AND VERMERSCH. BREUSTEDT reports a substantially smaller average relative variance reduction for 767 German wheat farms - 22.5% - for county yield insurance compared to rayon insurance.

The results for the weather index insurance schemes in Table 2 confirm the need for combining both approaches in the same manner as above. The performances of the analysed indexes are quite similar; their relative variance reduction is somewhat less than 30%, and is thus very similar to the relative variance reduction of the national yield insurance. However, the optimal coverage levels are substantially higher, with 1.4 – 1.5, on average, compared to around one in the case of area yield insurance schemes.

A more comprehensive comparison is carried out for a subsample of 36 farmers by means of bootstrapping because the assumption of identically and independently distributed time detrended yield and weather index insurance data cannot be rejected. We compare an area yield insurance (rayon) and weather index insurance (SELYANINOV index) both with a strike level of 100% of the expected value, and with the highest average relative variance among their type of insurance. We use farm yield insurance with a strike yield of 75% of the expected yield, which is equal to US standard farm yield insurance. The relative variance reduction is highest for rayon yield insurance for both the MV and SSD approach. Looking at the significance level of the expected variance reduction, farm yield insurance outperforms the other selected insurance schemes. Only one farm does not have a 5%-significant variance reduction in both the MV and SSD approach, while only 22 (15) farmers have a significant variance reduction by means of rayon (SELYANINOV index) insurance with the SSD approach. Two results remain. First, the risk of facing a 25% yield shortfall is substantial for the wheat farms in Kazakhstan. Second, the basis risk is high for many farms using rayon or SELYANINOV insurance.

In Table 4 we have counted the number of farms that can generate a significantly higher variance reduction with one of the insurance schemes compared to others. By means of the MV approach, rayon (SELYANINOV) insurance is preferred by 17 (4) farmers, while farm yield insurance is preferred by one farmer over each of the other insurance schemes. The SSD approach provides another result. None of the farms significantly prefer either rayon insurance or SELYANINOV insurance over farm yield insurance, while 3 farmers prefer farm yield insurance over one of the other schemes.

Conclusions

We analysed area yield insurance contracts and weather index insurance contracts in terms of risk reduction for wheat farms in Kazakhstan over the period 1980-2002. We have combined the common mean-variance approach with a stochastic dominance approach to ensure the consistency of the empirical results with expected utility theory. We have compared whether a farmer prefers - statistically significantly - a certain insurance scheme over another by means of bootstrapping.

Results indicate (1) the need for combining both approaches, because for some insurance schemes, the MV results of one-third of the farmers not being consistent with EU theory are suspicious. (2) Bootstrapping shows that an expected positive variance reduction is not statistically significant for up to one-third of the farms. Both results indicate that previous methods probably overestimate the effectiveness of crop yield and weather index insurance schemes, in particular for insurance schemes with basis risk. From a practical point of view, (3) area yield insurance based on the rayon yield provides substantially higher variance reduction than reported in the literature, indicating that area yield insurance contracts might be more appropriate in Kazakhstan because of the high systemic yield risk there - an effect of exposure to drought. (4) Empirical results indicate that area yield insurance should be based on the rayon yield instead of the higher aggregated oblast or national yield. (5) There are no substantial differences in the results generated by means of different weather indexes. (6) However, compared to farm yield insurance with a low strike yield in order to reduce moral hazard, weather index insurance would be a reasonable alternative for farmers, particularly, if considering transition circumstances with limited availability and reliability of farm-level data.

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Tables

Table 1. Variance reduction for different area yields

area yield insurance (strike yield = expected yield) 75 farms	national		oblast		rayon	
	mean-variance	SSD	mean-variance	SSD	mean-variance	SSD
relative variance reduction (mean)	0.28	0.25	0.22	0.15	0.42	0.40
coverage level (mean)	1.09	0.89	1.01	0.60	0.97	0.88
farms with expected positive variance reduction	75	53	72	50	75	61

Table 2. Variance reduction for different weather indices

weather index insurance (strike value = expected value) 75 farms	rainfall		Selyaninov		Ped	
	mean-variance	SSD	mean-variance	SSD	mean-variance	SSD
relative variance reduction (mean)	0.28	0.25	0.29	0.26	0.28	0.25
coverage level (mean)	1.47	1.09	1.43	1.06	1.47	1.09
farms with expected positive variance reduction	73	55	74	56	73	55

Table 3. Comparison of farm yield, area yield, and weather index insurance

	farm (strike yield = 0.75 expected yield)		rayon (strike yield = expected yield)		Selyaninov (strike index value = expected value)	
36 farms	mean-variance	SSD	mean-variance	SSD	mean-variance	SSD
relative variance reduction (mean)	0.31	0.31	0.42	0.39	0.31	0.24
farms with expected positive variance reduction	36	36	36	30	36	26
farms with 95% probability of positive variance reduction	35	35	34	22	35	15

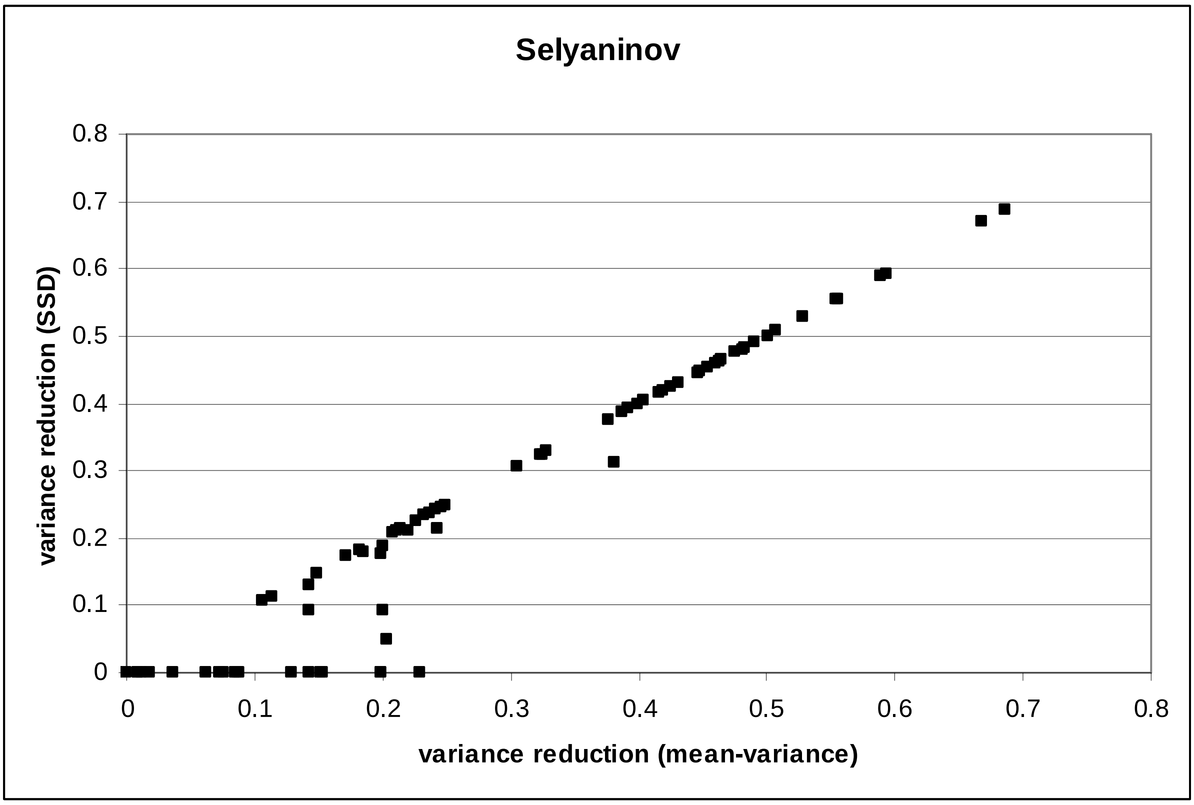
Table 4. Pairwiseed comparison of farm yield, area yield, and weather index insurance

			farm insurance	rayon insurance
	36 farms	strike level (of expected value)	75%	100%
mean-variance	rayon insurance	100%	17 / 1	
	selyaninov index	100%	4 / 1	0 / 0
SSD	rayon insurance	100%	0 / 1	
	selyaninov index	100%	0 / 2	0 / 4

First (second) number of a pair indicates number of farms that get a significantly higher (95% probability) variance reduction with the instrument in the row (column) than with the instrument in the column (row).

Graphs

Graph 1. Comparison of variance reductions by mean variance and by SSD approach



24 of 75 farms differ more than 1%-point in their variance reduction by mean-variance and stochastic dominance optimisation, respectively.